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Inter- and Intra-plate deformation at North American plate boundaries

Semi-annual report to Grant NAG5-799
July 1 - December 31, 1986

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Objectives

The project is divided into five sections:

1. Alaska tectonics and earthquake hazard studies.
2. Southern California tectonics - block rotation.
3. Spreading near the Salton Trough.
4. California plate motion - fault zone kinematics.
5. Caribbean plate motion investigations.

Results

During the current reporting period, we have made progress in objectives 1, 2 and 5 above. We describe our results below.

1. Alaska. Results from the first three years of the Alaska campaign were reported by Clark et al. (1986). Clark (pers. comm.) has provided us with a subset of the Alaska and Pacific baseline results, and we have used the observed motion of Sand Point to help place constraints on whether the eastern part of the Shumagin seismic gap is or is not slipping aseismically. Savage and Lisowski (1986) argued recently that the most likely interpretation of their 1980-1985 trilateration data was for plate motion to be occurring aseismically. If slip is occurring aseismically over the whole down-dip width of the plate interface then Sand Point is expected to remain stationary with respect to interior Alaska, and to move at a rate consistent with the full North America - Pacific plate motion towards sites such as Vandenberg and Hawaii. If the plate boundary is locked, then Sand Point should experience northwestward motion of about 1 cm/yr according to dislocation models (Savage, 1983) of strain accumulation. A map of the Shumagins is shown in Figure 1, predicted crustal motions from various models of subduction are shown in Figure 2, and a summary of all available observations is given in Table 1. Table 1 also compares the observed and predicted motions, where the aseismic model predicts zero deformation.

Using recent arguments on forearc mechanics (Byrne et al., 1986, 1987) we place the upper limit of the locked plate interface at ~20 km depth, whereas Savage and Lisowski (1986) place it at the surface. This leads Savage and Lisowski to substantially overstate their case for aseismic subduction. However, the balance of evidence,

Table 1. Comparison of Observed and Modelled Deformation

	Observed 1980-86	Elastic rebound models Figure 2b	Figure 2a	Savage
Strain, μstrain/yr				
Inner islands	-0.01±0.03	-0.02	-0.06	-0.07
Outer islands	0.03±0.05	-0.05	-0.22	-0.30
Tilt, μrad/yr				
SDP/SQH	-0.34±0.17	-0.37	-0.03	0.1
PRS	0.09±0.16	-0.41	-0.36	-0.3
SAD	-0.14±0.25	-0.41	-0.36	-0.3
SIM/SMH	-0.06±0.15	-0.08	-0.07	0.2
CHN	0.43±0.15	-0.08	-0.07	0.2
Displacement, cm/yr				
SIM-PRC uplift	0.4±0.7	-2.1	-1.2	-1.2
NW velocity of SDP	-0.9±0.9	1.0	1.2	-

Figure 2b model is locked between 25 and 50 km depth
Figure 2a model is locked between 20 and 50 km depth
Savage and Lisowski's model is locked from the surface to 50 km depth
Extensions are positive, tilts down to the NW are positive
Displacements upwards or to the NW are positive
Errors quoted are 1 standard deviation

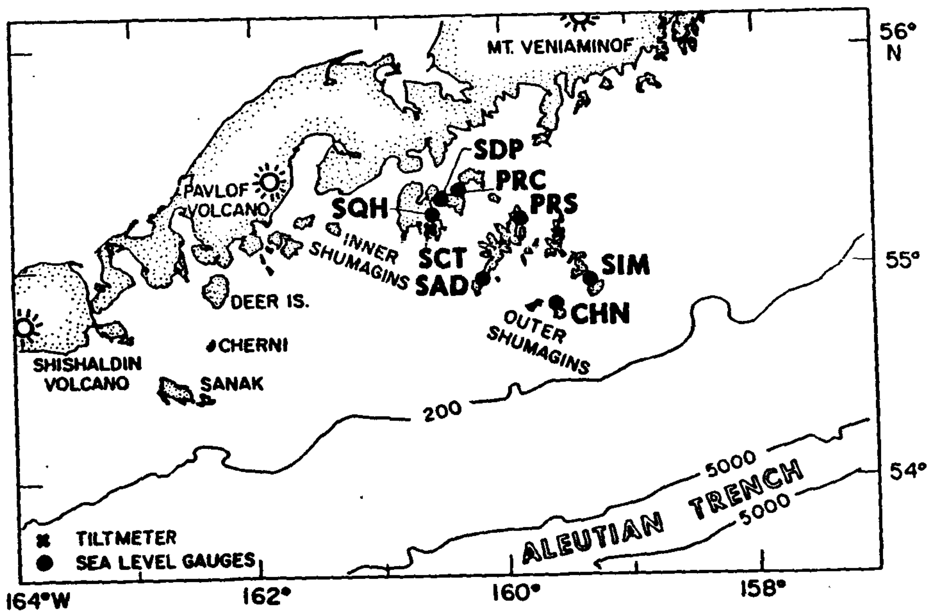
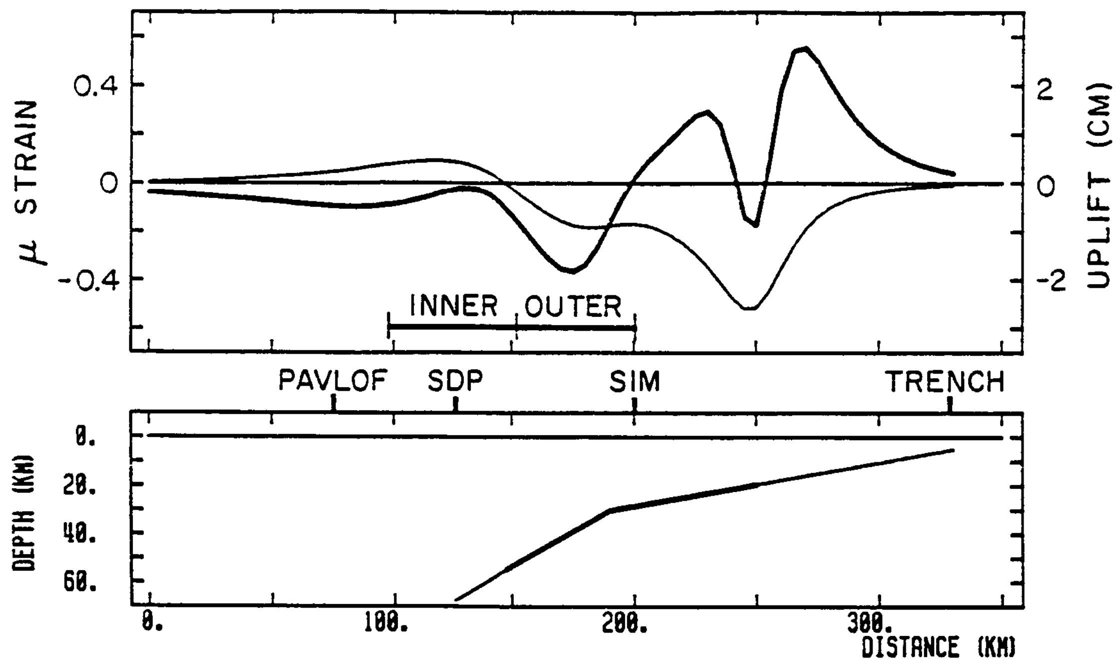


Figure 1. Location of the Shumagin Islands with respect to the trench and the volcanic arc. Depth contours are in metres. The Shumagin seismic gap extends from just east of the Shumagin Islands themselves, to the vicinity of Sanak Island in the west. Note the locations of Pavlof Volcano and the Inner and Outer Shumagins. The USGS trilateration network extends from the Outer Shumagins to the Alaska peninsula. Also shown are the sites of NASA VLBI measurements (SDP) and of sea-level gauges operated by Lamont-Doherty and by the National Ocean Survey (SDP). Station SAD is no longer operated because of repeated storm damage. Station PRS is not operating this year. Site CHN failed after 2 months due to a (rare) pressure sensor failure. Site SQH failed in October 1986 after 26 months of low-maintenance operation. Sites PRC and SIM continue to operate as of this writing. All sea level sites now use Paroscientific quartz pressure sensors. Note that none of the current geodetic measurements extend into the western part of the gap.



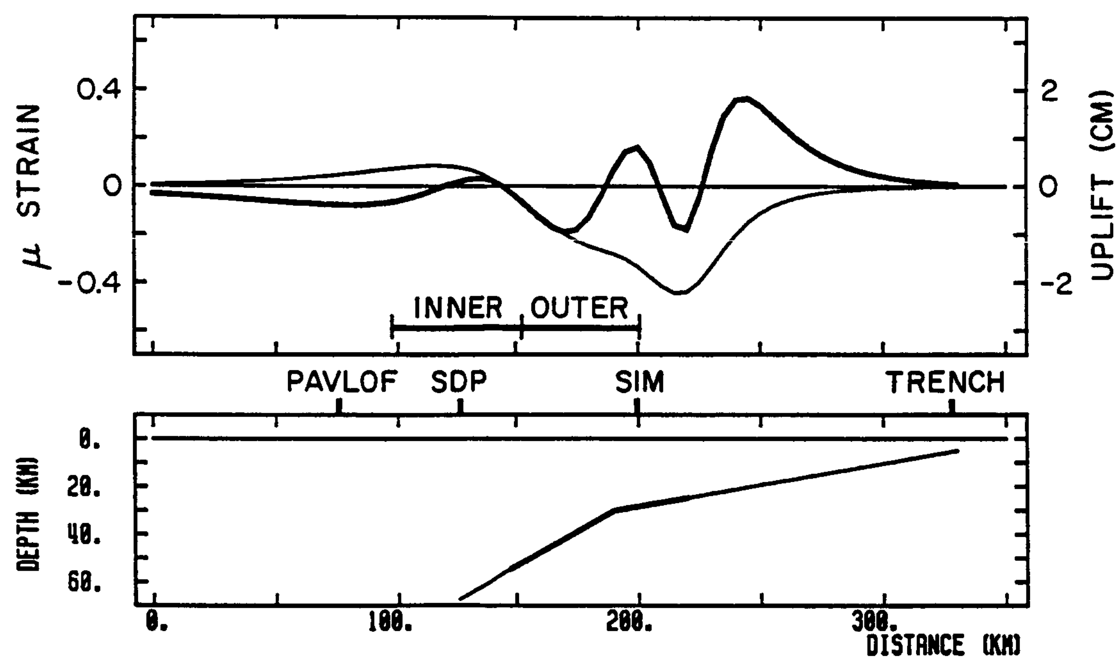


Figure 2 (a,b). Dislocation models showing surface uplift (thin line), and horizontal linear strain in the plate convergence direction (heavy line), due to strain accumulation, assuming a 7.5 cm/yr plate convergence rate (Minster and Jordan, 1978). The strongly coupled (locked) part of the plate interface is shown by the heavy line in the lower frame. The upper and lower limits of the locked zone are taken from seismic and forearc mechanics evidence (see text). Ground extension is positive. Table 1 compares the models with strain, tilt and displacement observations. Aseismic subduction would predict zero ground displacement.

including the VLBI data, is still that the *eastern* Shumagins are indeed behaving aseismically. We note that several of the observations have rather large error bars, and that a few more years of observations should substantially improve our knowledge of the important question of whether the subduction in this region is aseismic or whether a major earthquake may soon be expected.

We emphasise that these results place no constraints on deformation in the western part of the Shumagin seismic gap. Historical evidence (Davies et al., 1981) is strongly in favor of at least one major earthquake in this region, so that aseismic subduction throughout the whole gap is most unlikely. Recent seismic studies (Hudnut and Taber, 1987) suggest that the character of the gap changes between the eastern and western sections. The western section shows a clear double-planed seismic zone in the downgoing slab, whereas the eastern section shows only a single plane. The double-planed zone has been interpreted elsewhere (e.g. Astiz and Kanamori, 1986) as indicative of strong plate coupling, and thus of great earthquake potential.

2. *Block rotation in Southern California*

Paleomagnetic data suggest that significant rotations have taken place in California. If any VLBI or SLR sites are on rotating blocks then the details of the rotation may be very important in interpreting the data. The Ocotillo site is a clear example of a station that is located on a rotating block.

We are taking advantage of some existing astro-azimuth data to compare short-term geodetic rotation rates with long-term paleomagnetic rates in the Borrego Badlands area, which the paleomagnetic data suggest is rotating at perhaps 0.5 μrad/yr, due to its location between the San Jacinto and Clark faults. The Clark Lake basin, next to the Badlands (Figure 3) may be similarly rotating. A geodetic network has been measured here several times since the late 1950's, including measurements of angles to Polaris. The advantage of the measurements to Polaris is that the geodetic network can be referenced to an external frame, so that rigid body rotation can be determined. The disadvantage is that the determination is only good to ~5 μrad standard error, so that many years' measurements are required to detect the expected rotation rates of 0.3 to 1.0 μrad/yr. We remeasured part of the 'T' array (Figure 3) in December 1986 using a Wild T-2 theodolite. Initial results suggested measurable rotation, but this was defined by only a few benchmarks and the standard error of the survey was several times worse than expected. We plan to repeat and extend these measurements soon using a superior instrument (Wild T-3).

5. *Caribbean tectonics*

Dr. Bilham, co-investigator on this grant, participated in the June 1986 Caribbean GPS experiment organised by NASA/JPL. Three University Navstar Consortium receivers were donated to the project.

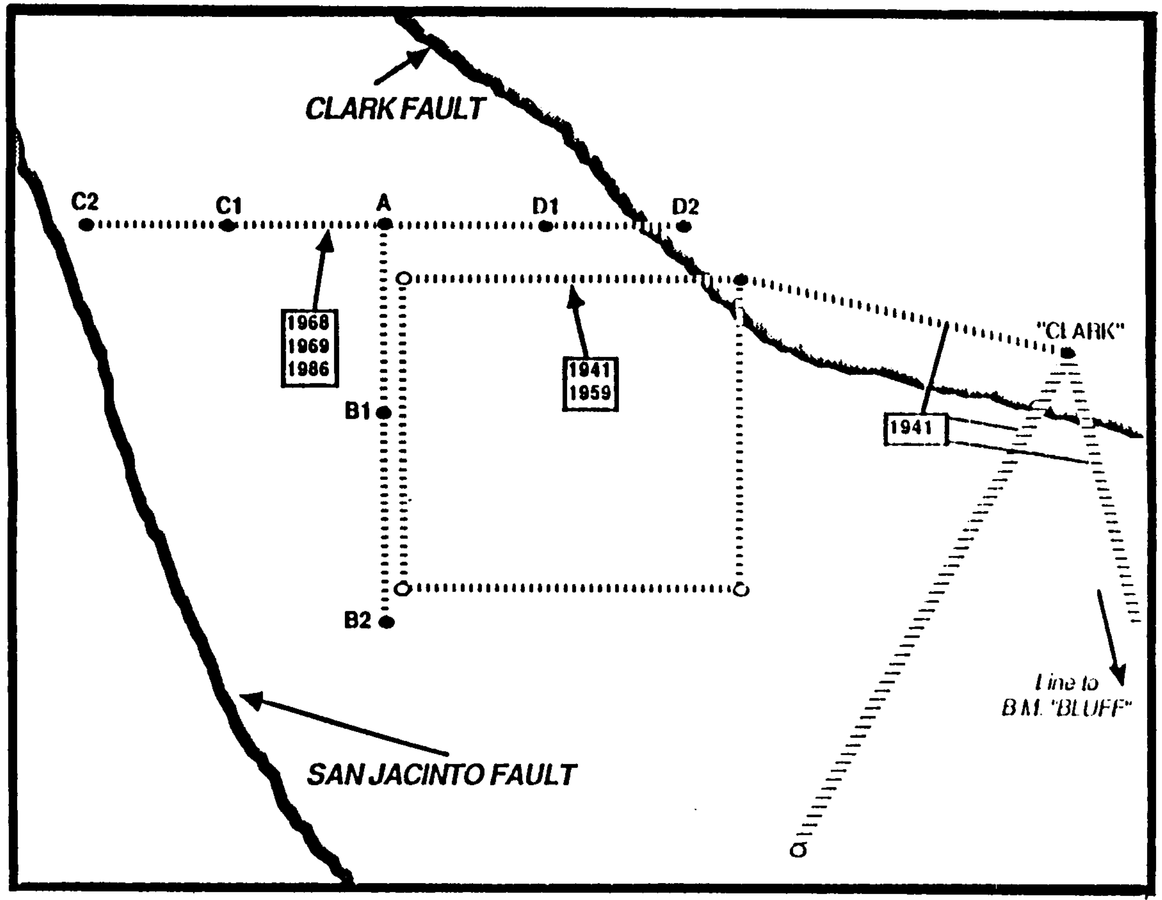


Figure 3. Clark Lake Radio Observatory geodetic arrays. We are using these historic geodetic baselines for astroazimuth determinations of block rotation. The arrays are unique in southern California, since they were established with direct reference to Polaris; this makes possible to directly measure block rotations relative to an external reference frame. The Southern California Trilateration Network, operated by the USGS, cannot uniquely resolve rotations, as we can do here. The T-shaped array lies along a large radio antenna; the E/W leg of the 'T' is ~3km long, and the N/S leg is ~1.5 km. Dates of surveys for each network are shown: the 'T' array was surveyed originally in 1968/69, and again by us in 1986 (both times referenced to Polaris). The square array was originally surveyed in 1941 (not a Polaris survey) and again in 1959 (referenced to Polaris).

Future Work

Dr. Bilham recently left Lamont for a professorial position at the University of Colorado, so he will no longer serve as co-investigator on this grant. As a result we will eliminate our efforts under Objective 5 above, and will redirect our efforts under Objectives 3 and 4. A specific data set that we shall study over the next few months is a suite of triangulation measurements done in the 1880's, 1920's and several times since then, that extends east from the San Francisco Bay area to the California - Nevada border. This data set has never been studied in its entirety, and it may throw light on where the "missing 2 cm/yr" of plate motion is taken up in northern California.

Papers in press

The following papers resulting from NASA support have been published during the past year, or are in press.

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